

Total J/ψ production cross section at the LHC

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We evaluate the production cross section for direct J/ψ integrated in P_T for various collision energies of the LHC in the QCD-based Colour-Singlet Model. We consider the LO contribution from gluon fusion as well as the one from a fusion of a gluon and a charm quark from the colliding protons. The rapidity distribution of the yield is evaluated in the central region relevant for the ATLAS and CMS detectors, as well as in the more forward region relevant for the ALICE and LHC-b detectors. The results obtained here are compatible with those of other approaches within the range of the theoretical uncertainties which are admittedly very large. This suggests that the “mere” measurements of the yield at the LHC will not help disentangle between the different possible quarkonium production mechanisms.

1 Introduction

In 2007, the first evaluations of QCD corrections to quarkonium-production rates at hadron colliders became available. It is now widely accepted – and understood – that α_s^4 and α_s^5 corrections to the CSM¹ are fundamental for understanding the P_T spectrum of J/ψ and Υ produced in high-energy hadron collisions,^{2,3,4,5,6,7} while the difficulties of predicting these observables had been initially attributed to non-perturbative effects associated with channels in which the heavy quark and antiquark are produced in a colour-octet state^{8,9,10,11}. Further, the effect of QCD corrections is also manifest in the polarisation predictions. While the J/ψ and Υ produced inclusively or in association with a photon are predicted to be transversally polarised at LO, it has been recently emphasised that their polarisation at NLO is increasingly longitudinal when P_T gets larger.^{4,5,12,13,14}

In a recent work,¹⁵ we have also shown that hard subprocesses based on colour singlet $Q\bar{Q}$ configurations alone are sufficient to account for the observed magnitude of the P_T -integrated cross section. In particular, the predictions at LO¹ (Fig. 1 (left)) and NLO^{2,3,4} accuracy are both compatible with the measurements by the PHENIX collaboration at RHIC²⁰ within the present uncertainties.^a The compatibility between the LO and NLO yields provided some indications that the computations are carried in a proper perturbative regime, at least at RHIC energies. The agreement with the data is improved when hard subprocesses involving the charm-quark distribution of the colliding protons are taken into consideration. These constitute part of the LO (α_s^3) rate (Fig. 1 (right)) and are responsible for a significant fraction of the observed yield.¹⁵

^aAs recently noted,¹⁵ this points at a reduced impact of the s -channel cut contributions¹⁶ as well as of the colour-octet mediated channels relevant for the low P_T region. The latter are anyway very strongly constrained by very important recent e^+e^- analyses¹⁷ which leave in some cases no room at all for colour octets of any kind.

We proceed here to the evaluation the P_T -integrated yield at higher energies both in the central and forward rapidity regions. While we find a good agreement with CDF data,¹⁸ our study shows that the theoretical uncertainties become very large –close to one decade– reminiscent of the case of total charm production.¹⁹ Besides, the yield coming from gluon-charm fusion is shown to remain a visible fraction of the direct yield at the LHC energies. Finally, we shortly discuss the impact of higher QCD corrections and the comparison with other approaches.

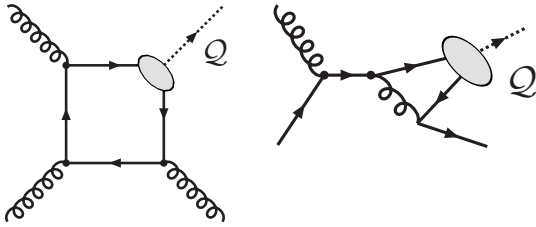


Figure 1: Representative diagrams contributing to 3S_1 charmonium hadroproduction at high energies in the CSM by gluon fusion (left) and initiated by a charm quark at order α_S^3 .

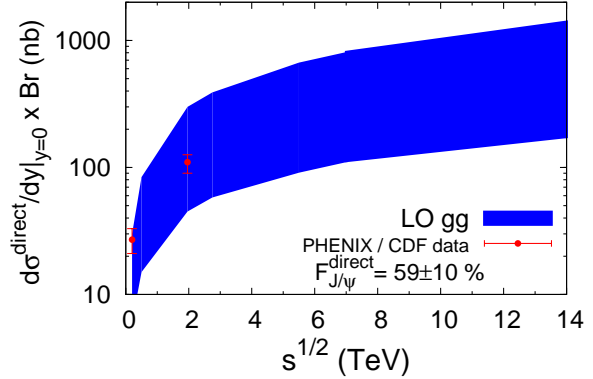


Figure 2: $d\sigma_{J/\psi}^{direct}/dy|_{y=0} \times Br$ from gg fusion in pp collisions for \sqrt{s} from 200 GeV up to 14 GeV compared to the PHENIX²⁰ and the CDF¹⁸ data multiplied by the direct fraction.

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The P_T integrated cross sections obtained here have been evaluated along the same lines as our previous study.¹⁵ The uncertainty bands have been evaluated following exactly the same procedure using the same values for m_c , μ_R and μ_F .

In Fig. 2, we show $d\sigma_{J/\psi}^{direct}/dy|_{y=0} \times Br$ from gg contributions as function of \sqrt{s} from 200 GeV up to 14 TeV compared to the PHENIX²⁰ and the CDF¹⁸ data multiplied by the direct fraction^b. We have found a good agreement. At larger energies, these results at 7 TeV (100 to 800 nb) and at 14 TeV (200 to 1400 nb) are in the same range as those of the Colour Evaporation Model²⁴ with central (upper) values of 140 nb (400 nb) at 7 TeV and 200 nb (550 nb) at 14 TeV. They are also compatible with the results of the "gluon tower model" (GTM)²¹, 300 nb at 7 TeV and 480 nb at 14 TeV, which takes into account some NNLO contributions shown to be enhanced by $\log(s)$. Quoting the authors,²¹ "the expected accuracy of the prediction is about a factor of 2-3 in either direction or even worse."

In Fig. 3, one shows the differential cross section in rapidity from both gg and cg contributions (separately and then summed) at $\sqrt{s} = 7$ TeV. One sees that the contribution from cg is not negligible. To be more quantitative, we have computed the ratio $(d\sigma_{J/\psi}^{cg}/dy)/(d\sigma_{J/\psi}^{cg+gg}/dy)$ for $m_c = 1.4$ GeV using 3 choices of the charm distribution in the proton²² and taking uncorrelated values for μ_R and μ_F for both contributions. At large rapidity, one starts to see the enhancement of BHPS²³ $c(x, Q^2)$ for $x > 0.1$. Fig. 5 and Fig. 6 show the same contributions at $\sqrt{s} = 2.75$ TeV and $\sqrt{s} = 14$ TeV.

^bNote that the measurement of the prompt yield by CDF went only down to $P_T = 1.25$ GeV. We have assumed a fraction of non-prompt J/ψ of 10% below.

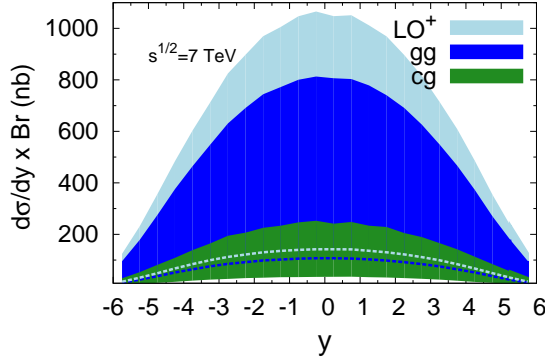


Figure 3: $d\sigma_{J/\psi}^{direct}/dy \times Br$ from gg fusion (dark blue), from cg fusion (green) and from all the LO contributions (light blue) in pp collisions at $\sqrt{s} = 7$ TeV.

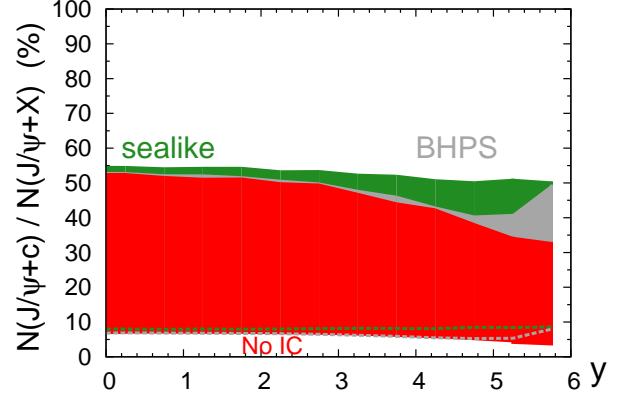


Figure 4: Ratio $(d\sigma_{J/\psi}^{cg}/dy)/(d\sigma_{J/\psi}^{cg+gg}/dy)$ at $\sqrt{s} = 7$ TeV for $m_c = 1.4$ GeV for uncorrelated values of μ_R and μ_F for gg and cg contributions and for 3 $c(x, Q^2)$: NoIC (red), sealike (green) and BHPS (gray)

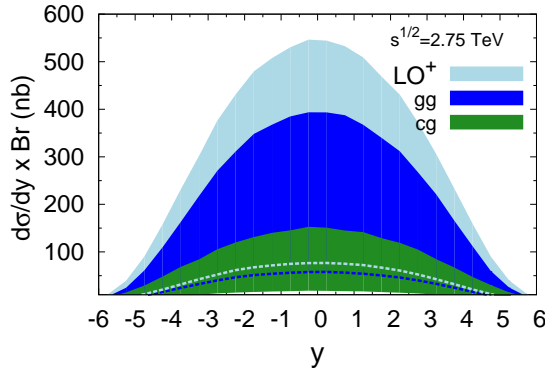


Figure 5: $d\sigma_{J/\psi}^{direct}/dy \times Br$ from gg fusion (dark blue), from cg fusion (green) and from all the LO contributions (light blue) in pp collisions at $\sqrt{s} = 2.75$ TeV, i.e. the $\sqrt{s_{NN}}$ planned for Pb+Pb collisions in 2010.

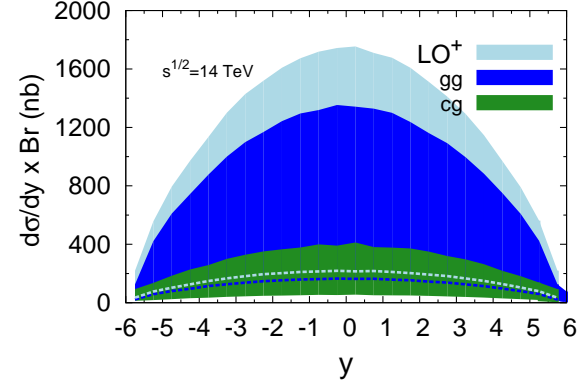


Figure 6: $d\sigma_{J/\psi}^{direct}/dy \times Br$ from gg fusion (dark blue), from cg fusion (green) and from all the LO contributions (light blue) in pp collisions at $\sqrt{s} = 14$ TeV.

3 Discussion and conclusion

Let us now discuss briefly the expectations for the results when QCD corrections are taken into account. First, we would like to stress that, although NLO results² are perfectly well behaved in nearly all of the phase space region at RHIC energies,¹⁵ it seems not to be so for larger s . One observes that the region where the differential cross section in P_T and/or y is negative (i.e. very low P_T and large y) widens for increasing s . Negative differential cross section at low P_T is a known issue. Nonetheless, for \sqrt{s} above a couple of TeV, and for some (common) choices of μ_F and μ_R , the P_T -integrated “yield” happens to become negative, even in the central region. This can of course be explained by a larger contribution from the virtual corrections at α_S^4 —which can be negative—compared to the real emission contributions—which are positive—. Naturally, such results cannot be compared to experimental ones. This also points at likely large virtual NNLO contributions at low P_T ; these are not presently known. Yet, as already mentioned, specific NNLO contributions were shown²¹ to be enhanced by $\log(s)$.

As we have discussed above, one may try compare the LO CSM with other theoretical approaches such as the CEM²⁴ and the GTM²¹. They all qualitatively agree, as well as with

PHENIX and CDF measurements. For all approaches, one expects a significant spread –up to a factor of ten – of the results when the scales and the mass are varied.

Owing to these uncertainties, it will be difficult to discriminate between different mechanisms by only relying on the yield integrated in P_T and even, to a less extent, on its P_T dependent counterpart. This is a clear motivation to study at the LHC other observables related to the production of J/ψ such as its production in association with a single charm (or lepton),¹⁵ with a prompt isolated photon^{12,13} or even with a pair of $c\bar{c}$.³

Acknowledgments

I would like to thank the organisers for inviting me to their lively conference. I thank V.Khoze, A. Kraan, M. Ryskin, G. Smbat, R. Vogt for correspondences and F. Fleuret for useful discussions.

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